Criticality of Gust Pressures on the Members of Self Standing Towers

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***Abstract:*-Tall latticed steel towers are being pursued for the purpose of microwave transmission, T.V. transmission etc. Antennas are fixed at the top of the tower for transmission. The height of the towers may range from 50m to 250m. The structural form consists of latticed steel work, suitable bracing and suitable foundation for the tower legs. Usually bolted connections are provided for the joints. Mainly dead and wind loads are considered for the design of such towers. The I.S. Code [8] has given recommendations for force coefficients to be adopted while estimating the wind force. The force coefficient depends on the solidity ratio. The design wind pressure is multiplied by the effective frontal area and the force coefficient to arrive at the wind force. The code is silent on the method to be followed to determine the design wind pressure. The latticed steel towers which have lesser self weight relative to the height are highly flexible in nature and under the action of the fluctuating wind the towers vibrate and undergo large deflections or deformations. Hence the study of wind-structure dynamic interaction becomes necessary for accurate assessment of wind effects on towers. The gust effectiveness factor takes into account the dynamic properties of the structure, the wind-structure interaction and then determines the wind loads as equivalent static loads. In this paper, steel towers of heights ranging from 50m to 250m are considered for wind load analysis. Wind loads are determined based on static method as well as gust effectiveness factor method. The critical gust loads for design are determined. The variation of wind force with height, geometry and the dynamic properties of the structure are studied. Based on the above, important conclusions are drawn. The conclusions will be useful for safe and rational design of latticed steel towers.**

***Key words:*- Gust Pressures, Frequency, Resonance**

I. INTRODUCTION AND REVIEW

Steel lattice towers are used in several applications like electrical transmission, microwave communication, lighting towers etc. As the height becomes more, the tower becomes more flexible and the tower structure will interact with the fluctuating component of the wind. Scruton [1,2] discussed the wind effects on tall stacks, towers, masts, tall buildings blocks, cooling towers and suspension bridges. Davenport [3] discussed the response of structures to gusty wind. The author discussed the response of small point like structures to wind turbulence, the aerodynamic admittance function, gust response factors, the response of slender line like structure, properties of joint acceptance functions cross wind response, aerodynamic damping etc., Badruddin Ahmed et al [4] discussed the behavior of self supporting towers under the wind loads. The authors analysed some existing towers and compared the results with the measured data. Satisfactory agreement was obtained for across wind response. Deoliya et al [6] conducted the reliability analysis for a 75m tall microwave antenna tower for the variable mean wind speed. The authors are of the opinion that the probability of failure of tower is increased for a wind climate in which the mean wind velocity fluctuation has large coefficient of variability which means the design based on n year design wind speed concept will be less for certain wind climates. Celio.F.Carril [7] studied the effect wind forces on the rectangular latticed communication towers with antennas. The authors analyzed the wind incidence angle, the tower solidity, the shielding effect and the influence of the wind turbulence on the drag coefficient. The obtained results were compared with the existing International codes. The authors concluded that there is no difference in mean drag coefficient from turbulent and smooth flow and also these valves agreed with codal valves. But there are differences between measured shielding factors and those predicted by the codes. The lattice towers having solidity ratio of 0.2 or less should use interference factor of 1.0

II. WIND LOADS AS PER I.S. CODE

The Code [8] discusses about the two methods. The static method, which is commonly used considers the structure as rigid and ignore its dynamic properties. In the Gust Effectiveness factor method the dynamic interaction between the wind and the structure is considered and the resulting pressures are expressed as equivalent static loads. Hence there is a need to study the criticality of wind on towers by applying the Gust Effectiveness Factor method.

A. Basic wind speed

Basic wind speed is based on peak gust velocity averaged over a short time interval of about 3 seconds and corresponds to mean heights above ground level in an open terrain. The basic wind spee d from IS code [8] for Hyderabad is 44 meters per second, and the basic wind speed of other places are given in tables of the code.

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III. WIND PRESSURES AS PER IS CODE [8]

Wind pressures acting at any height on a structure are computed by the methods recommended by the IS Code [8]. The code has recommended two methods for computing the wind pressures based on the requirement.

IV. CALCULATION OF LOADS

A. Dead loads

The tower dead loads are taken from structural steel section (steel tables) i.e, IS hand book for structural engineers.

B. Live loads

Live loads on towers are negligible and hence they are neglected here (assuming live loads are included in dead loads itself).

C. Wind loads

The gust wind loads are computed and applied to towers as nodal loads and analysis is carried out for two different load cases for the computation of axial forces in various members.

D. Load combinations

Three load combinations are considered for the analysis here.

1) 1.5*D.L(Assuming live loads are included)
2) 1.5*(D.L+W.L)
3) 0.9*D.L+1.5*W.L

E. Plane dimension tower analysis

Plane dimensional tower analysis is performed for towers ranging from height 50m to 250m which has 90% accuracy compared to 3-Dimensional tower analysis, otherwise 3-Dimensional analysis is a tedious process and becomes acute as the tower height increases. The crucial observation for performing the plane dimension tower analysis is "Wind at a particular time will act only from one direction and the structure being symmetrical" as such wind will not act simultaneously from more than one direction. So a plane dimension tower analysis is sufficient which gives more accurate results and also reliable. Hence, keeping all in view a plane dimension tower analysis is conducted and the axial forces are obtained in different members of the self standing towers ranging from 50m to 250m height.

V. DETAILS OF THE PRESENT STUDY

The present study deals with the computation of wind pressures on steel towers of various heights. The wind pressures are computed by using both the methods as already described. Steel towers with heights from 50,100,150,200 and 250m are considered for wind pressure analysis to highlight the criticality of the gust loads.

VI. DISCUSSION OF THE RESULTS

In the conventional design, wind loads on the towers are considered as static loads. This approach is valid only up to limited height. As the height of the tower increases its aspect ratio increases and the tower becomes more and more flexible. Due to the flexible nature of the tower there is possibility for the fluctuating wind component to interact with the flexible tower. Due to the interaction between the wind and the structure, critical effects like increasing pressures, large displacements may be produced in the tower. Thus the wind effects become critical for the design of tall towers.The gust effectiveness factor takes into account the dynamic interaction between the wind and the structure.

A. Static wind pressures

The pressures are computed as per IS code [8]. The factor K_1 is assumed to be 1.07(Since for towers the life of the structure is assumed to be 100 years) and K_3 is taken to be unity. The factor K_2 is taken from the table of IS code [8]. Category 3 is assumed for all the towers. The static pressure considers the basic wind speed and the height of the structure for given terrain. The pressures do not depend on the nature of the structures. All types of the structures are considered as rigid for the estimation of static pressures. The static wind pressure varies from 894.25 N/m^2 at 5m height to 1551.21 N/m^2 at 50m height for a 50m tower. There is a variation of 73% in the pressure from bottom to the top of tower. Similarly the static wind pressure varies by 77%, 96%, 106% and 114% for 100m, 150m, 200m and 250m height towers respectively from bottom to top. The details of wind pressures for typical 150m tower are shown in Table 1.

B. Variation of fundamental frequency

When the frequency of the structure is lower because of the flexibility, there is a possibility of the structure interacting with the wind dynamically. In extreme cases when the frequency of the wind and the structure match, resonance takes place leading to large displacements and the eventual failure of the structure. The gust effectiveness factor takes into account the mean and the resonance component of the fluctuating wind for determining the gust effects on the structure. For studying this effect, the fundamental frequency of the structure together with the wind spectral energy is required. Hence in the wind structure interaction problem the fundamental frequency play an important role.

C. Gust factor

The values of the Gust factor decreases with increasing height of the tower. In the case of 50m tower the gust factor is 2.52 whereas for 250m it gets reduced to 1.94. The values of the Gust Factor are shown in Tables 2.

TABLE I: VALUES OF GUST FACTOR

S. No.	Tower Height from Base (m)	Rayleigh Frequency Values (CPS)
1	50	2.52
2	100	2.27
3	150	2.15
4	200	2.00
5	250	1.94

D. Gust Pressures

The Gust Pressures are found to increase with the height. In the case of 150m height tower the Gust Pressures are found to increase from 714.82 N/m^2 at 10m height to 2003.15

N/m^2 at 150m height. The increase is of the order of 180%. Similarly for other towers the increase is found to be 83% 147%, 208% and 230% for 50m, 100m, 200m and 250m height towers respectively. The variation of Gust Pressure with height for 150m height tower is shown in fig.1. The computed wind pressures for a 150m tower are shown in table 1.

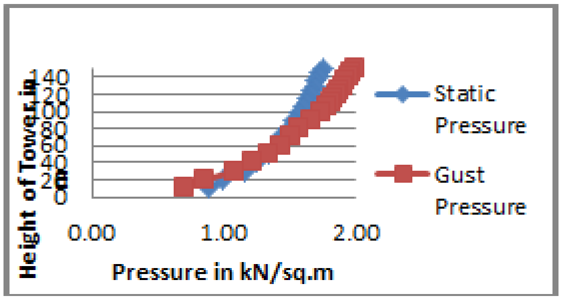

Fig.1. Variation of Pressure with Height for 150 m Tower

E. Comparison of gust pressure and static pressure

The Gust pressures are found to be considerably higher compared to Static Pressures in the case of towers of various heights ranging from 50m to 250m but more predominant for the towers with height more than 100m. For example in the case of a 150m tower the static pressure is 1,751.17N/m ² at the top where as the gust pressures is 2,003.15N/m² at top, hence the gust pressures is more by nearly 10% compared to static pressure for a 150m tower. The variation is shown in the fig 1. Similar is the observation in all other cases. So it is quite clear that the gust pressures are critical for design in the case of towers of height more than 100m.

F. Comparison of wind forces

In the case of 50m tower the difference in the wind forces at the top is 3% where as at the top of 250m tower the difference in wind forces is 12%.Considering a 150m tower the forces increases with height up to 60m and then decrease with height up to 150m, because of slope provided to the tower legs and the change in the geometry of the tower. There is a considerable difference in the value of wind force components at various joints between static and gust. Because of this there will be considerable difference in the values of axial forces in the different members of the towers. This will be critical for the design.

G. Comparison of axial forces in horizontal members

The computed axial forces in the members of typical 150m tower are shown in table 3. The axial forces in the vertical members of 150m towers are plotted in fig.2.Comparing the values it can be seen that the horizontal force is increasing from top to bottom. At top, in the range of 100 to 250m height towers the axial forces produced due to gust is constantly increasing from top to bottom. The axial force produced in 150m tower at 10m height is 124.01kN where as it is getting reduced to 16.85kN at 150m height, which means there is a reduction from bottom to top. Hence it is clear that gust forces are producing considerably higher values of axial forces in the horizontal members. Hence it may be concluded that the structural design based on static forces is unsafe.

H. Comparison of Axial Forces in Diagonal Members

For a typical 150m tower, the axial load is 44.49kN at 150m height on the leeward side which is under compression and getting increased to 220.65kN at 10m height. Comparing the values it can be seen that the diagonal forces are increasing from top to bottom. At top, in the range of 100 to 250m height towers the axial forces produced due to gust is constantly increasing from top to bottom. Hence it is clear that gust forces are producing considerably higher values of axial forces in the Diagonal members.

I. Comparison of axial forces in vertical members

The vertical legs of a tower are most important in the structural frame work of the tower. If the vertical leg fails due to inadequate design, the whole tower would collapse. The comparison of axial forces produced in the vertical member of the towers for 150m tower is shown in Table 3. The axial forces in the vertical members become critical due to wind effects. In the case of 150m tower, the maximum axial compression in the leeward member under the dead load effect is 325.27kN. This value goes up to 2809.29kN when wind is added. In the windward member there is a tensile axial force of -2158.75kN at the base of the tower. The variation is shown in fig 2. The variation is similar in the case of remaining towers also. Hence wind effects are highly critical for the design of vertical legs of the tower. The vertical members are to be designed for maximum compression under dead and wind load combination and are to be checked against tension. To safeguard the legs against the tension heavy raft foundations are to be provided and the legs are to be suitably anchored to the foundation. The axial forces produced due to gust are increasing from top to bottom especially for towers of more than 100m in which the dynamic analysis controls the design. For the design of vertical legs of the tower gust effectiveness factor method is giving considerably higher value of axial forces. Hence it is clear that for the safe design of vertical legs of a tower the axial forces given by gust loading are to be considered.

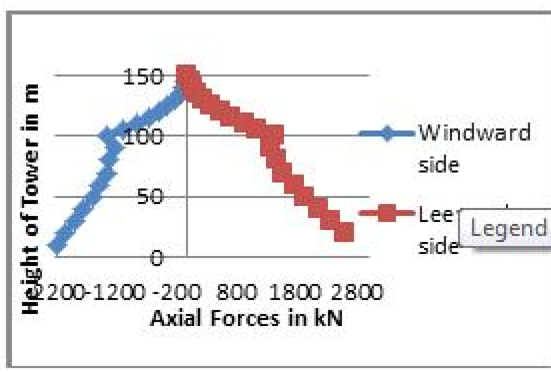

Fig.2. Axial Forces in Vertical Members for 150m Height Tower

VII. CONCLUSIONS

- There is a variation of nearly 96% in static pressure from bottom to top of 150m tower. But in the case of gust pressure there is an increase of nearly 180% from bottom to top.

- In the wind-structure interaction problem, the fundamental frequency plays an important role. Instead of adopting an approximate value of the fundamental frequency it is better to use exact computed value by using appropriate software package.
- Though the gust pressures have increased with height, this increase becomes slower as the height of the tower is increased. The values of gust factors remain constant and are computed for the maximum height. Because, of this rapid increase in the value of mean wind pressures with height, the overall gust pressures increase with height. But the increase will become slower with height.
- The gust pressures are considerably higher compared to static pressures, in the case of latticed towers of various heights ranging from 50m to 250m and become more predominant for towers of height greater than 100m in which dynamic analysis controls the design. From this it is quite clear that the gust pressures are critical for design in the case of tall lattice towers.
- There is considerable difference in the values of wind force components at various joints between static and gust. Because of this there will be considerable difference in the values of axial forces in different members of the towers which will be critical for design.
- The structural design based on static forces is unsafe for tall structures more than 100m. For a safe design gust pressures are to be adopted as they produced more axial forces in the horizontal & diagonal members of the towers.
- For the design of vertical legs of the tower gust effectiveness factor method is giving considerably higher values of axial forces. Hence it is clear that for the safe design of vertical legs of a tower the axial forces given by gust loading are to be considered.

For a more realistic and safe design of the tower gust effects are to be considered.

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TABLE II WIND LOADS ON 150M TOWER

Panel No.	Tower Height From Base(m)	Solidity Ratio $Ø = A_e/A_g$	Force Coefficient (C_f)	Effective Frontal Area(A_e/4) (m^2)	Static Wind Pressure pz (N/m^2)	Gust Wind Pressure GPZ(N/m^2)	Static Wind Force F= $A_eC_f$pz/4 (kN)	Gust Wind Force F= A_eC_fGPZ/4 (kN)
1-1	150	0.265	2.97	0.635	1,751.17	2,003.15	3.302	3.777
2-2	145	0.265	2.97	0.635	1,735.94	1,979.28	3.273	3.732
3-3	140	0.265	2.97	0.635	1,720.78	1,955.57	3.245	3.688
4-4	135	0.265	2.97	0.635	1,705.69	1,931.99	3.216	3.643
5-5	130	0.265	2.97	0.635	1,690.66	1,908.56	3.188	3.599
6-6	125	0.265	2.97	0.635	1,675.70	1,885.27	3.160	3.555
7-7	120	0.265	2.97	0.635	1,660.80	1,862.12	3.132	3.511
8-8	115	0.265	2.97	0.635	1,645.97	1,839.12	3.104	3.468
9-9	110	0.265	2.97	0.635	1,631.21	1,816.26	3.076	3.425
10-10	105	0.265	2.97	0.635	1,616.52	1,793.54	3.048	3.382
11-11	100	0.211	3.25	1.26	1585.87	1744.07	6.494	7.141
12-12	90	0.352	2.54	2.98	1,539.74	1,664.60	12.003	12.599
13-13	80	0.279	2.90	3.01	1,494.29	1,586.99	13.043	13.852
14-14	70	0.233	3.13	3.05	1,449.52	1,511.23	13.837	14.426
15-15	60	0.201	3.30	3.08	1,405.43	1,437.32	14.284	14.607
16-16	50	0.178	3.41	3.12	1,343.24	1,341.66	14.290	14.274
17-17	40	0.160	3.50	3.16	1,264.25	1,226.72	13.982	13.567
18-18	30	0.146	3.57	3.20	1,162.64	1,081.46	13.281	12.354
19-19	20	0.135	3.62	3.24	1,006.67	864.94	11.807	10.144
20-20	10	0.113	3.80	3.11	894.24	714.82	10.568	8.447

TABLE NO III AXIAL FORCES IN 150M TOWER

Tower Height From Base(m)	Axial Forces in Vertical Members				Axial Forces in Horizontal Members		Axial Forces in Diagonal Members			
	Wind- -ward 1.5*DL (kN)	Leeward (1.5*D.L) (kN)	Wind ward 1.5*(D.L+W.L) (kN)	Leeward 1.5*(D.L+W.L) (kN)	1.5*D.L (kN)	1.5*(D.L+W .L) (kN)	Windward (1.5*D.L) (kN)	Leeward (1.5*D.L) (kN)	Windward 1.5*(D.L+W.L) (kN)	Leeward 1.5*(DL +L.L) (kN)
150	+2.78	+2.78	-2.78	+2.78	0.00	+16.85	+1.53	+1.53	-41.83	+44.49
145	+7.07	+7.07	-36.73	+49.19	-0.26	+8.16	+1.53	+1.53	+41.83	+44.49
140	+11.36	+11.36	-74.57	+95.61	-0.26	+8.16	+1.53	+1.53	+41.83	+44.49
135	+15.64	+15.64	-112.41	+142.08	-0.26	+35.79	+1.53	+1.53	+112.25	+114.92
130	+19.93	+19.93	-219.31	+257.50	-0.26	+21.98	+1.53	+1.53	+112.25	+114.92
125	+25.47	+25.47	-325.75	+374.23	-0.26	+43.44	+2.12	+2.12	+166.50	+170.23
120	+31.59	+31.59	-484.48	+545.19	-0.37	+32.60	+2.12	+2.12	+166.50	+170.23
115	+37.70	+37.70	-643.20	+716.15	-0.37	+53.54	+2.12	+2.12	+219.88	+223.61
110	+43.82	+43.82	-854.27	+939.45	-0.37	+43.07	+2.12	+2.12	+219.88	+223.61
105	+49.94	+49.94	-1,065.34	+1,162.75	-2.56	+66.34	+2.12	+2.12	+279.22	+282.94
100	+61.60	+61.60	-1,334.17	+1,451.51	-2.56	+11.77	+4.96	+4.96	+101.60	+92.95
90	+83.84	+83.34	-1,221.12	+1,378.01	-0.35	+48.12	+8.49	+8.49	-90.71	+105.92
80	+109.64	+109.64	-1,290.98	+1,499.52	-0.20	+14.13	+8.68	+8.68	-52.18	+67.77
70	+135.65	+135.65	-1,322.37	+1,582.92	-0.59	+94.89	+8.90	+8.90	-178.97	+194.99
60	+161.88	+161.88	-1,474.60	+1,787.62	-0.99	+43.57	+9.14	+9.14	-127.52	+144.02
50	+188.64	+188.64	-1,575.32	+1,941.85	-1.39	+122.78	+9.71	+9.71	-210.65	+228.30
40	+219.90	+219.90	-1,749.85	+2,176.32	-1.78	+69.25	+12.00	+12.00	-163.30	+185.10
30	+253.28	+253.28	-1,874.52	+2,367.76	-2.81	+137.05	+12.38	+12.38	-216.77	+239.34
20	+268.98	+268.98	-2,044.07	+2,604.91	-3.36	+87.98	+12.80	+12.80	-178.95	+202.35
10	+325.27	+325.27	-2,158.75	+2,809.29	-3.79	+124.01	+15.74	+15.74	-191.77	+220.65

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